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Physical and biological changes of the Antarctic sea-ice habitat during early summer in the Weddell Sea

In order to investigate the role of physical and biological atmosphere-ice-ocean interactions in global processes in the western Weddell Sea (Antarctica) during early summer, an expedition called ISPOL (Ice Station Polarstern) with RV "Polarstern" has been initiated. The multi-national, interdisciplinary expedition was carried out from November 2004 to January 2005 and involved a 40-day drift station in the western Weddell Sea (Fig. 1). This Antarctic sea-ice region comprises the largest perennial ice zone of the Southern Ocean, which exerts a major influence on the oceanography, meteorology and ecology in this region. In the following preliminary cruise results of the sea ice group of the Institute for Polar Ecology (Kiel) are presented.

Figure 1 *Aerial photograph of the ISPOL drift-ice station in the western Weddell Sea (28. Nov. 2004 to 2. Jan. 2005).*

Time series study

In order to determine temporal changes of the sea-ice habitat and the under-ice habitat during the transition between winter and summer, chemical, physical and biological properties were investigated in a time series study ("TS"). For this purpose, an undisturbed sampling site of 12 x 12 m, chosen at the beginning of the ice station, was sampled every 5 to 6 days in a fixed sampling design (Fig. 2 and 3). Many institutions contributed to this interdisciplinary study and investigations, which were conducted by the sea-ice group of the Institute for Polar Ecology, included measurements of ice thickness, ice temperature, bulk salinity, chlorophyll a concentration (chl a) as well as the determination of abundance and distribution of sympagic meiofauna organisms. Small-scale distributions of abiotic (temperature, chl a concentration, salinity) and biotic properties

(abundance and distribution of zooplankton organisms) of the under-ice habitat were investigated by use of an under-ice video system and an under-ice pump system.

SEA ICE HABITAT

All ice cores taken at the same sampling day were drilled within an area of 2 x

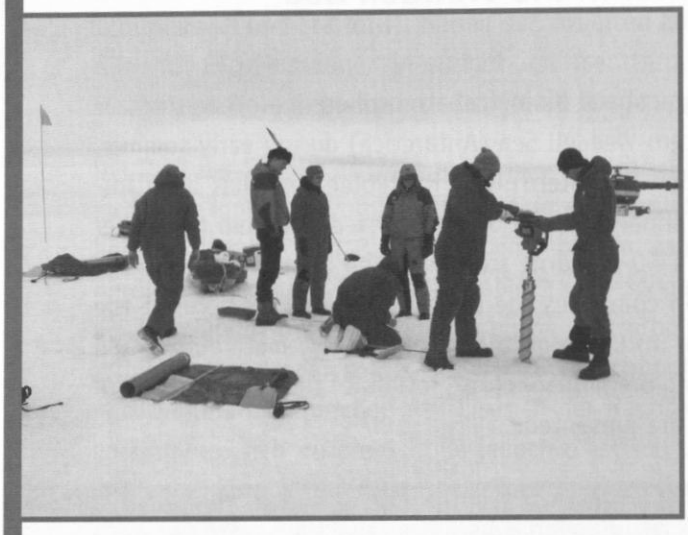

Figure 2 *Ice floe sampling during the ISPOL expedition in the western Weddell Sea.*

2 m to minimize spatial heterogeneity (Fig. 3). Ice thickness was determined as the mean length of all drilled cores, whereas ice temperature was measured at only one core. Ice temperature was measured immediately after drilling with a Testotherm 720 thermometer inside small holes, drilled into the core at 5 cm intervals. Chlorophyll a concentration and bulk salinity were determined for three cores (Fig. 3). After drilling, the ice cores were cut into 1–10 cm segments

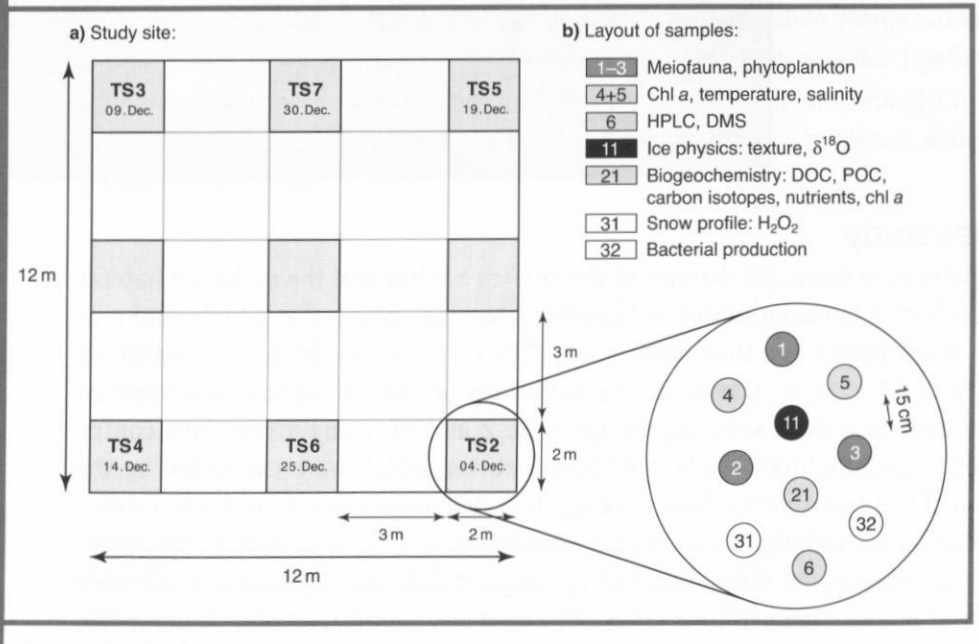

Figure 3 *Sampling scheme of the study site (a) and the lay-out of samples (b) of the time series (TS) study. Station TS 1 was taken at a location different from that of succeeding TS stations.*

(Fig.4), placed into cleaned polyethylene-boxes and melted onboard at 4 °C in the dark. Once melted, bulk salinity was measured with a WTW 190 conductometer. Based on ice temperature and bulk salinity measurements, brine salinity was

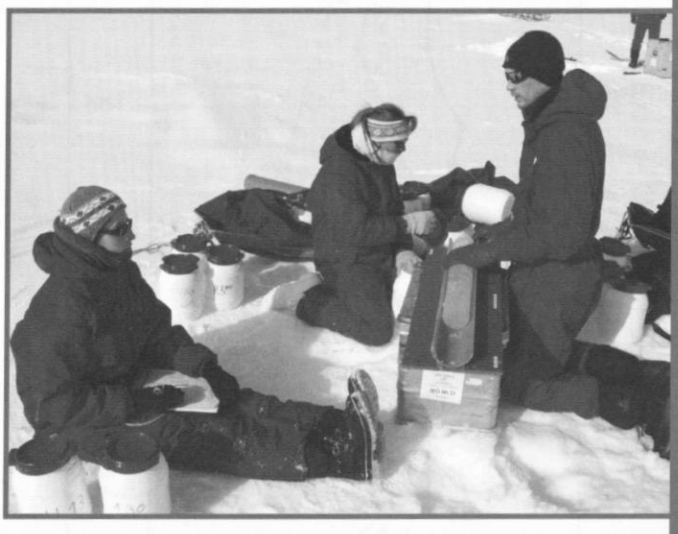

Figure 4 *Processing of ice cores during the time series study.*

calculated as a function of ice temperature, and brine volume was calculated as a function of bulk ice salinity and ice temperature.

For the determination of chlorophyll a concentrations the melted ice samples were filtered onto Whatman GF/F filters, extracted in 90% acetone, homogenized and analyzed fluorometrically with a Turner Designs 10-AU digital fluorometer. Detection limit of this method is 0.1 µg chl a l-1. Meiofaunal investigations were conducted on three cores (Fig. 3). After cutting in 5–10 cm, all segments were melted in the dark at 4 °C in addition of 0.2 µm filtered deep-seawater to avoid osmotic stress. Once melted, all samples were concentrated over a 20 µm gauze and the samples of two cores were fixed for later analyses with buffered formaldehyde (1% final concentration). The samples of the third core were sorted out under a stereo microscope (10–50 fold magnification) onboard.

Results

Ice temperature

Ice-core temperatures measured at the first four stations (TS 1 to TS 4) were mostly between -2.0 and -2.5°C (Fig. 5). From station TS 5 to TS 7 temperatures increased in the upper part of the ice cores reaching a maximum value of -1.1°C at the topmost ice segments (TS 7). Ice-core temperatures at the ice-water interface were rather constant during the course of the study ranging from -2.2°C (TS 4) to -1.9°C (TS 6 and TS 7).

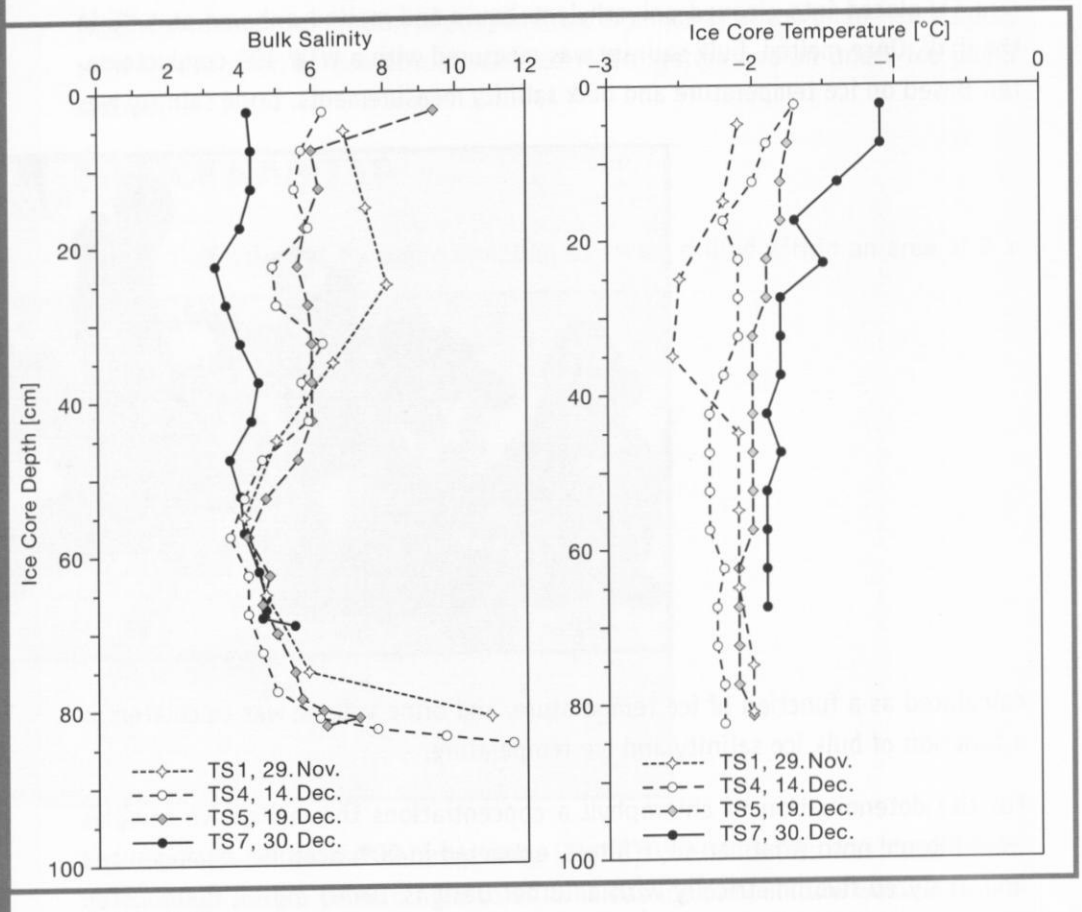

Figure 5 *Vertical profiles of bulk salinity and ice core temperature of four selected time series stations (TS 1, TS 4, TS 5 and TS 7).*

Bulk salinity

Bulk salinities measured in ice cores taken during the time series study ranged between 3.3 and 11.6 (Fig. 5). Salinity profiles for stations TS 1 to TS 4 were of similar shape, with bulk salinities of 5–8 within the uppermost 50 cm of the core and values of 3–5 between 50 and 70 cm depth. Below that depth, salinities did gradually increase towards the bottom of the ice cores reaching maximum values of ~11 at the lowermost segment.

Bulk salinities measured at station TS 5 were comparable to previous stations except for an abrupt salinity increase at the topmost section and a reduced salinity at the bottom of the ice core (Fig. 5). The last two stations of the time series study (TS 6 and TS 7) were characterised by a drop in bulk salinity values to ~4 for the upper 50 cm and further reduced salinities at the bottom of the ice cores.

Ice thickness

Thickness of ice cores taken during the time series study varied between 67 and 94 cm (Fig. 6). Within ice cores of the same sampling day thickness variability was generally ≤8 cm. Ice cores of station TS 1 (which were taken at a location different from that of succeeding TS stations) were lower in thickness (median:

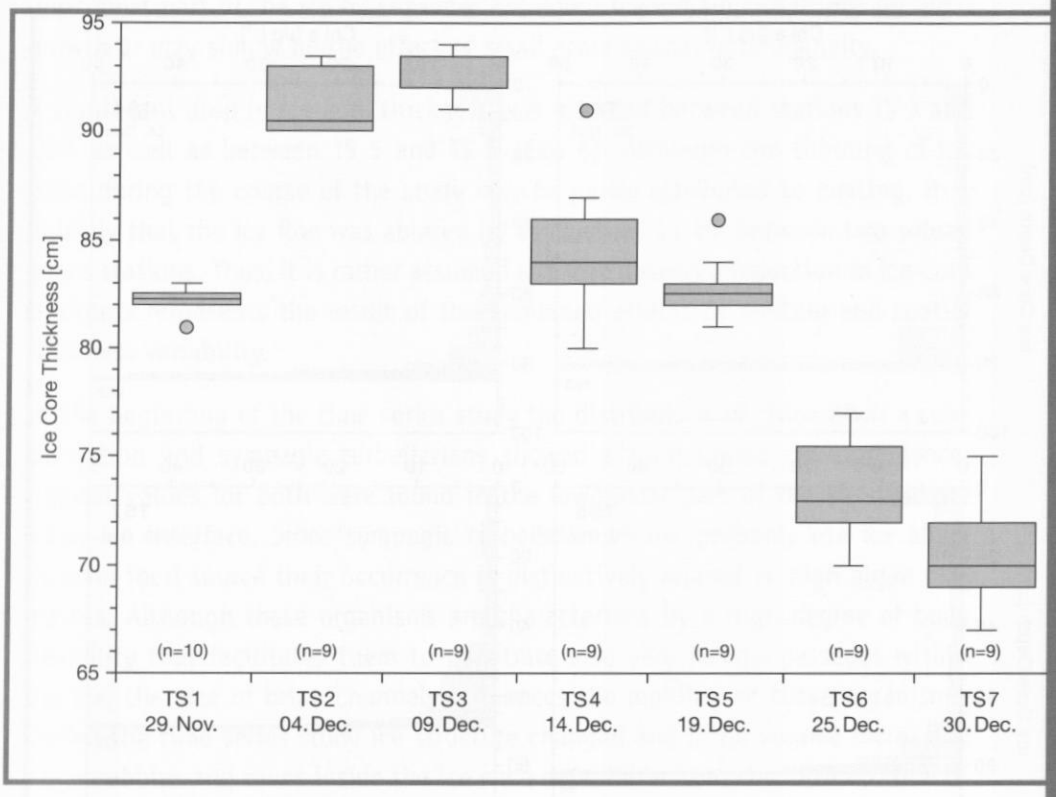

Figure 6 *Ice core thickness of all stations sampled during the time series study. Box plots show the total data range, the 25–75% quartile range and the median. Outliers are marked as single data points.*

82.3 cm) than cores of the following two stations (TS 2 and TS 3, medians: 90.5 and 92 cm, respectively).

Compared to stations TS 2 and TS 3, ice-core thicknesses of stations TS 4 and TS 5 (medians: 84.0 and 82.5 cm, respectively) were on average 8 cm lower. At the last two stations of the time series study (TS 6 and TS 7) ice cores were on average ~11 cm shorter than cores from stations TS 4 and TS 5 (Fig. 6).

Chlorophyll a

Time series cores analysed for chl a concentration revealed a pronounced bottom assemblage with mean chl a concentrations being one order of magnitude higher at the bottom decimetre than in any other segment of the core (Fig. 7). During the first four stations (TS 1 to TS 4) chl a concentrations within the upper 70 cm of the ice cores generally did not exceed 2.5 µg l-1. Mean chl a concentrations at the bottom decimetre of the ice ranged from 34.6 to 38.8 µg l-1 and a maximum value of 262 µg l-1 was recorded at the lowermost centimetre of station TS 4.

While chl a concentrations in the centre part of ice cores from stations TS 5 to TS 7 weren't particularly different from previous stations, mean concentrations at the bottom decimetre were considerably lower (17.3–20.3 µg l-1) and chl a values at the lowermost centimetre were only about half of what was measured at the first four stations (Fig. 7).

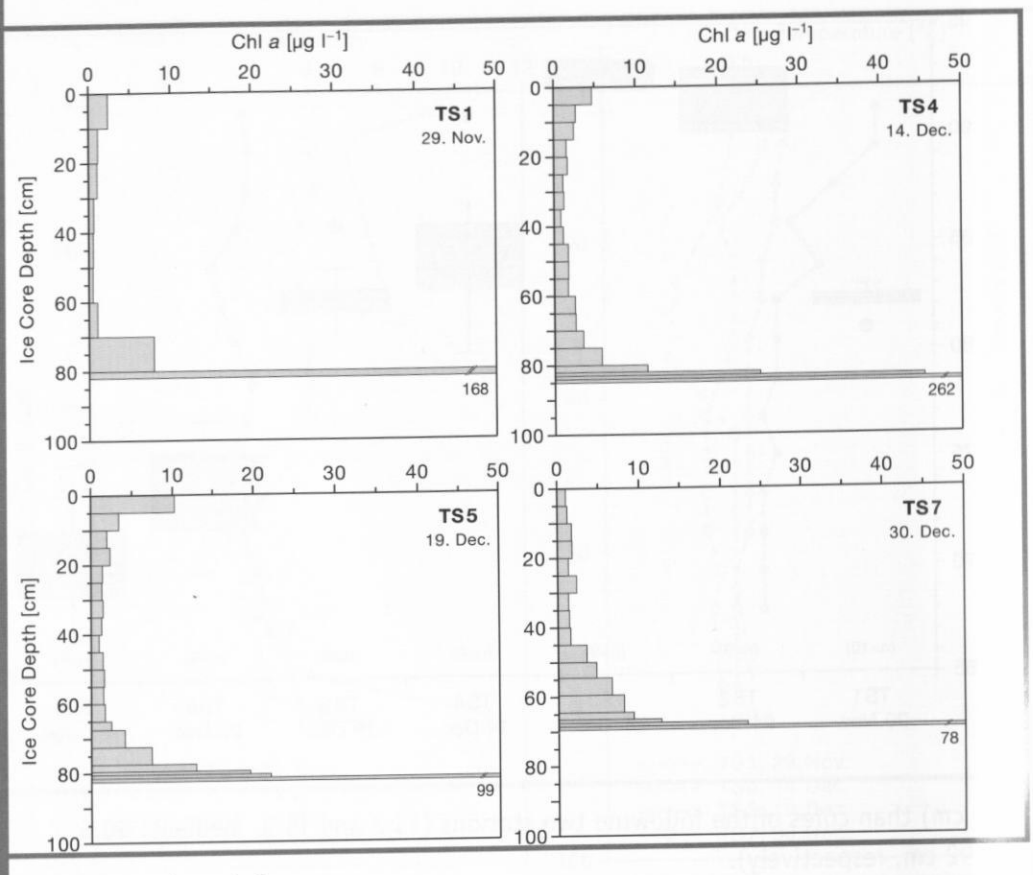

Figure 7 *Vertical distribution of chlorophyll a concentrations at stations TS 1, TS 4, TS 5 and TS 7 during the time series study.*

Sympagic meiofauna

In the beginning of the time series study the occurrence of sympagic turbellarians was almost restricted to the lowermost part of the ice (Fig. 8a). With the exception of single specimens, found in the upper part of the ice, organisms concentrated near the ice-water interface. Abundances ranged between 363 (TS 1) and 1075 individuals l-1 (TS 2) within the lowermost ice segments and decreased with time. However, starting from the fifth sampling day (December, 19th), turbellarians were also found in high abundances in the uppermost part of the ice (Fig. 8b).

Discussion

During the first four stations of the time series study chl a concentrations increased in the inner part of the ice as well as at the ice underside (Fig. 7). Beginning with station TS 5, considerably reduced chl a concentrations were observed at the lowermost two centimetres of the ice which may be attributed to melting at the ice underside and, as a result, algae being washed out to the water column. This is corroborated by the marked drop in bottom-ice salinity at station TS 5 as compared to the preceding stations (Fig. 5).

The uppermost 5-cm segment at station TS 5 showed an abrupt increase in salinity (Fig. 5) that corresponded to a double-fold increase in chl a concentration within the same segment. This observation could indicate flooding of the

uppermost part of the ice by seawater providing favourable conditions for algal growth or may simply be the effect of small-scale spatial heterogeneity.

A significant drop in ice-core thickness was recorded between stations TS 3 and TS 4 as well as between TS 5 and TS 6 (Fig. 6). Although the thinning of ice cores during the course of the study may be partly attributed to melting, it is unlikely that the ice floe was ablated by as much as 11 cm between two subsequent stations. Thus, it is rather assumed that the observed reduction in ice-core thickness represents the result of the combined effects of melting and spatial thickness variability.

In the beginning of the time series study the distribution of chlorophyll a concentration and sympagic turbellarians showed a pronounced correspondence. Highest values for both were found in the lowermost part of the ice near the water-ice interface. Since sympagic turbellarians most probably use ice algae as main food source their occurrence is distinctively related to high algae biomasses. Although these organisms are characterized by a high degree of body flexibility that facilitates them to penetrate also very narrow passages within the ice, the size of brine channels influences the mobility of these organisms. During the time series study ice structure changed and brine volume increased. Huge bubbles and caves inside the ice were detectable from station TS 5. Due to their high body flexibility turbellarians probably rather than sympagic copepods were able to descend higher into the ice and, thus, use food resources obtained in this upper part. Thereby, the organisms were furthermore able to avoid worsen environmental conditions near the ice-underside, e.g., caused by ongoing melting processes in the beginning of summer.

The results also indicate that total abundances of sympagic turbellarians did not change significantly with time but their distribution changed from an initial accumulation near the ice-underside to an enhanced spatial distribution of organisms during the course of the study.

UNDER-ICE HABITAT

The boundary layer between sea ice and the water column is a unique habitat with special abiotic (e.g. temperature, salinity) and biotic (e.g. food resources) factors, which also vary with season and region. In the Antarctic, studies of this special habitat are still scarce. Until now, krill (*Euphausia superba*) is the best described Antarctic species, which feeds in this habitat mainly during the winter season. Only one Amphipod species (*Eusirus antarcticus*), which lives in this environment, has been recorded until now.

Every five days, starting at the 29th of November, salinity, temperature and chlorophyll a concentrations were measured in the water column beneath the

ice. Additionally, at each sampling day the ice underside was recorded with an under-ice video system for one hour. In order to qualify and quantify the under-ice zooplankton (> 55 µm) an under-ice pump was used sampling water directly beneath the ice and at a depth of 5 m.

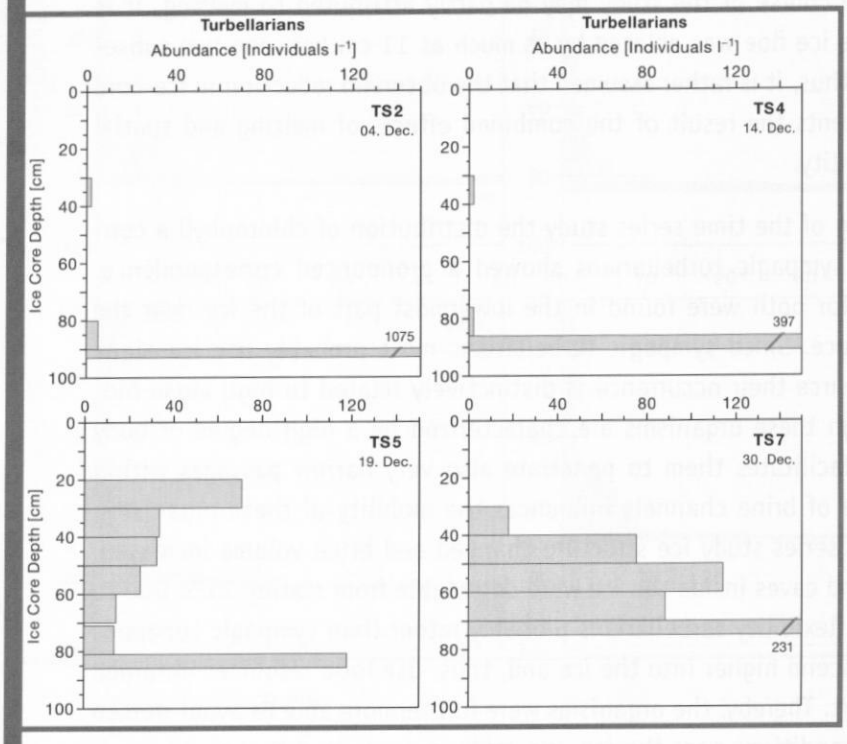

Figure 8 *Vertical distribution and abundance of sympagic turbellarians at stations TS 2, TS 4, TS 5 and TS 7 during the time series study.*

Results and discussion

It was possible to obtain five data sets at the same position on the one, the other two data sets were taken at different sites, due to ice dynamics, which crushed the first sampling site and made the access to the second site impossible at one occasion.

Temperature and salinity were measured in the first 8 metres below the ice (Fig. 9). During the first three stations, the under-ice water was always at the freezing point (e.g., TS 3) representing winter or early spring conditions. This was accomplished by the under-ice video images, which showed a smooth and level ice under-side.

From the 14th of December on temperatures in the first few decimetres under the ice rose slightly to -1.8°C and salinities declined to 34.6, indicating that some slight melting took place (e.g., TS 5 and TS 7). At the end of the measurement period also the under-ice video images showed a rougher under-ice surface with holes and depressions indicating melting at the ice-underside. The chlorophyll a concentrations slightly increased during the study from values of 0.1 µg/l at the ice underside and 0.1 µg/l five meters below, to concentrations of 0.3 µg/l at the ice underside and 0.2 µg/l five meter below. At one occasion an exceptionally high concentration of 2.3 µg/l was measured at the ice underside. This may be due to melting processes and the release of ice algae

into the water column. The overall slight increase in chlorophyll a concentrations may indicate the beginning of the ice-algal spring bloom. Analysis of the quantitative under-ice pump samples in the home laboratory will give an insight to the community structure of the under-ice zooplankton but also will reveal if a trend of increasing biomass can also be found in the under-ice fauna.

The Antarctic infiltration layer

Ice floes in the Antarctic often carry a large amount of snow, which results in a submerging of the sea-ice due to the weight of the snow. Thus, the snow is infiltrated by seawater, starting from cracks in the ice or directly through the ice if this is porous enough.

The seawater contains nutrients and algae, which find stable and favourable light conditions on top of the sea-ice. Therefore, high primary production can take place in this so-called infiltration or freeboard layer. Infiltration layers were already detectable during the crossing of the Weddell Sea at the beginning of the cruise, indicated by sometimes strongly brownish coloured ice edges.

In order to obtain sympagic copepods (*Drescheriella glacialis* and *Stephos longipes*) for experimental studies, sea-ice as well as infiltration layers were probed which partly contained astonishingly high numbers of these copepods. Furthermore, other species like sympagic turbellarians, ctenophores and nudibranchs were found. In order to describe the environmental parameters and to quantify biomass and species composition a patchiness study was performed. At several randomly chosen positions on the floe total snow thickness, thickness of the infiltrated layer, temperature, salinity and chlorophyll a concentrations in the infiltration layer were measured. Additionally, quantitative amounts of the infiltration layer were fixed for later analyses of the contained meiofauna. Samples were taken three times every five days to obtain also a temporal resolution. Due to the lack of continuous accessibility, not all samples could have been taken at the same sampling site as it was planned.

Temperatures within the infiltration layer varied from –2.0°C to –0.9°C with lower values at the beginning of the study (TS 5), and the salinity of the interstitial water ranged from 19.5 to 30.5. Lowest chlorophyll a concentrations of 0.7 µg/l were in the same range as those found in the under-ice water, whereas the highest chlorophyll a-value of 32.6 µg/l is about tenfold higher than values found in the seawater. Inspection of the samples for retrieval of experimental animals showed, that only the two copepod species mentioned above, one ctenophore species and different turbellarian species dominate the meiofauna of the infiltration layer. Two other copepod species and nudibranchs were only seldom found. Species composition showed a high spatial heterogeneity, especially with respect to the abundances of copepods and turbellarians.

Later analyses of species and stage composition of the taken meiofauna samples and comparison with samples taken from the ice and the under-ice water will show, if the infiltration layer plays an important feeding ground for the sympagic meiofauna.

Molecular-biological studies on sympagic organisms

During this cruise samples were taken to analyze adaptations of sympagic species to high salinities and low temperatures with molecular-biological methods.

The transcription of DNA to mRNA is the first step during the synthesis of proteins, which are the main effectors of physiological functions and adaptations. As the protein synthesis is energy demanding, it is very important for the cell to control this first step precisely. Therefore gene expression analysis is one of the first steps to understand physiological adaptation mechanisms on the transcriptional level. It will be searched for transcripts whose proteins are responsible for adaptations to the extreme habitat. Specimens of the copepod species Drescheriella glacialis and Stephos longipes were isolated mainly from the infiltration layer and incubated subsequently at different temperatures. For both species it was found, that they still actively swim at temperatures as low as -3.1°C and the corresponding salinity of 55. Underneath this temperature their activity strongly declines. Therefore about 1600 specimens per experiment and species were incubated at different salinities and temperatures: 400 specimens at -3.1°C and S = 55, 400 specimens at -1.2°C and S = 55 and 800 specimens at -1.2°C and S = 55 for at least two days.

From these different groups mRNA will be isolated and it will be searched for differentially expressed genes using a molecular-biological technique called "suppression subtractive hybridization". The group, which encountered high salinities but no low temperatures functions as a control to find genes which are only strongly expressed due to salt stress. Thereafter the differentially expressed transcripts will be furthermore characterised with different molecular-biological methods.

Another side aspect of this project will be the sequence- and expression analysis of sodium potassium ATPase in both sympagic copepod species.

Under-ice amphipods in the Antarctic pack-ice zone

The Antarctic under-ice fauna is commonly believed to consist mostly of krill (*Euphausia* spp.) and copepods, while amphipods seem to play a minor role and have only occasionally been reported from the pack ice zone. The aim of the cruise was first of all to verify this assumption, i.e. to check whether there also were any amphipods under the pack ice of the western Weddell Sea, and secondly, whether they could be considered truly sympagic organisms, i.e. that they could be observed living close to and attached to the underside of the ice.

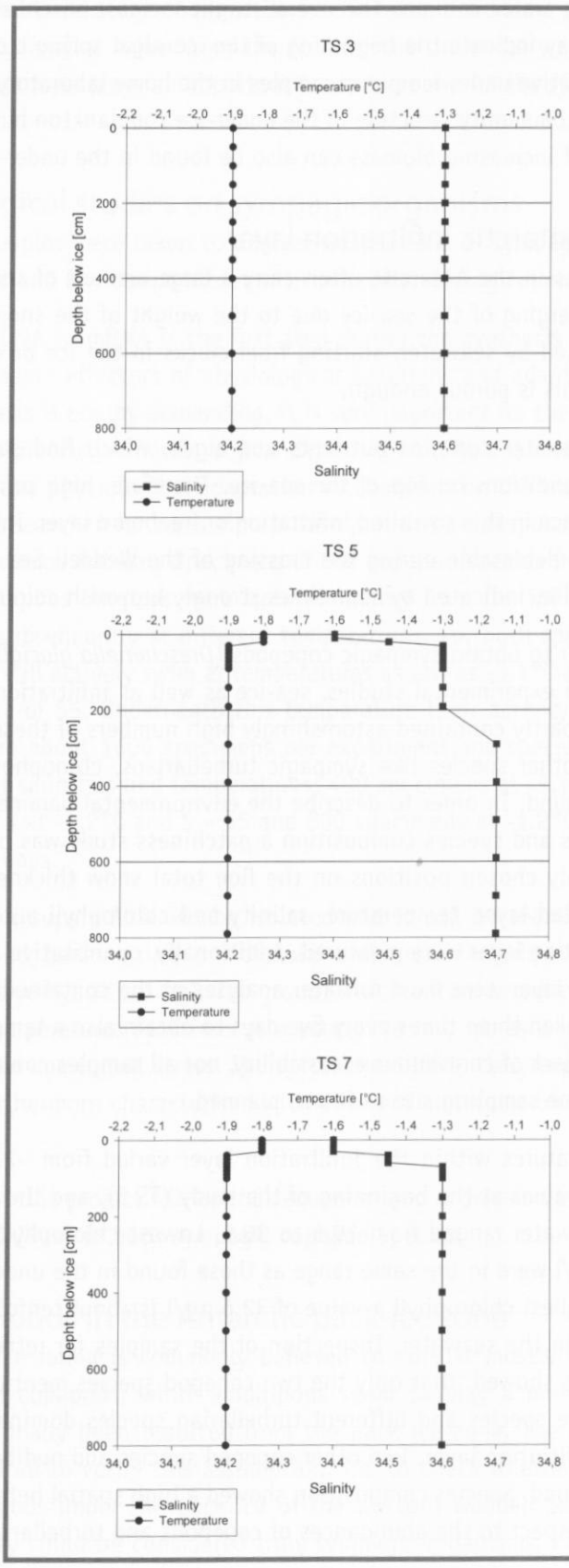

Figure 9 *Vertical profiles of salinity and temperature in the under-ice water at stations TS 3, TS 5 and TS 7 during the time series study.*

Another goal was to measure ultraviolet radiation (UVR) at the sea ice surface and underside in different places to measure the penetration of this potentially harmful radiation under different ice types and thicknesses. This should then be combined with the findings of under-ice fauna sampling to test whether the UV radiation might have an impact on these organisms, or whether the ice provided sufficient cover and protection. Previous studies have indicated that UV can be an important ecological factor even under sea ice, and have pointed to certain pigment compounds, the mycosporine-like amino acids (MAA's) as a possible source of UV protection, since these pigments absorb at different wavelengths in the UV range. So sampled organisms were to be tested for total pigment content as well as MAA content, to address both the aspect of their food selection and possibly also MAA accumulation through intake of MAA-producing microalgae, notably diatoms.

Sampling was mainly based on conventional scuba- and rebreather diving, allowing the deployment of sampling gear and sensors selectively and accurately under the sea ice, as well as visually observing and recording the habitat and its fauna. Rebreather diving was the preferred choice of sampling, since it reduced the amount of disturbing exhaled air to an absolute minimum, while the time the diver could work underwater was greatly prolonged, due to the effective use of the recycled breathing gas. Another sampling method was the deployment of baited traps through core holes in the ice, as well as from the floe edge. A total of six dives were performed, during which two types of amphipods were observed and sampled under the ice. Sampling was performed using a hand-held dip net. These amphipods were identified as truly sympagic organisms, since they could be observed both in the habitat as well as in the aquarium as they were sitting attached to and even crawling into the ice under-surface. Later, samples from the infiltration layer revealed that they also reached this area of the ice floe, either by passing through larger vertical brine channels or by entering this layer horizontally. A first taxonomic analysis revealed that these amphipod types most probably belonged to the family Eusiridae, which matches previous observations of Eusirid species under Antarctic ice, though from other regions.

Another amphipod type was observed in the baited traps several times, where the previously mentioned Eusirid amphipods occurred only once. These amphipods were of a distinctively different type, namely of the family Lysianassidae, but since they were only found in the baited trap deployments and not in the under-ice net samples, it could not be determined whether they could also be considered as sympagic or rather sub-ice fauna. Laboratory observations in cooled aquaria showed no active attachment to the ice, while the previously mentioned Eusirid specimens readily and actively sought the attachment to pieces of ice when being offered this as substrate.

Apart from sampling individuals for total pigment and MAA content, several respiration and feeding experiments were performed, whose results will first

be accessible after subsequent laboratory analysis and calculations. Preliminary observations revealed a carnivorous and even cannibalistic feeding mode for the Eusiridae, while data on the diet composition of the Lysianassidae as well as on the uptake of phytoplankton remain to be analysed. If possible, lipid analysis of all amphipod types will also be performed and could give additional information on that subject.

Due to the restricted possibility of sampling, the systematic measurement of UV penetration through the ice was limited to one transect, but more extensive measurements of surface irradiance and snow cover penetration were performed instead. The planned in-situ and laboratory experiments with artificial UV irradiance using lamps and the modification of artificial or natural light fields by means of filters had to be abandoned due to insufficient sample amounts.